Lower atmosphere studies

Temporal variation of snow accumulation rate at two Ross Ice Shelf locations influenced by katabatic winds

DAVID A. BRAATEN, *Department of Physics and Astronomy, University of Kansas, Lawrence, Kansas 66045*

The time-dependent processes of ice-sheet snow accumulation in two windswept areas on the Ross Ice Shelf were investigated between January 1994 and November 1995 using the automated microsphere dispersal system (MDS) to disperse colored glass microspheres onto the snow surface at preset time intervals to act as a tracer (Braaten 1994, 1995). Study sites were Willie Field automatic weather station (AWS) (77.85°S 167.08°E) and Ferrell AWS (78.02°S 170.80°E). Each AWS provides measurements of meteorological parameters (Holmes, Stearns, and Weidner 1993) every 10 minutes, and at Willie Field only, snow depth measurements with an accuracy of ±10 millimeters were made using a Campbell Scientific ultrasonic snow-depth gauge and a CR10 datalogger with a data storage module (provided by C.R. Stearns). Willie Field AWS and Ferrell AWS have characteristically different wind regimes, although both sites experience katabatic winds and are close enough to be influenced by the same synoptic scale storms. Willie Field winds are moderated by the proximity to the topographic features of Ross Island, White Island, and Black Island, with 21.2 percent of the observations exceeding 5 meters per second (m s^{-1}) (approximate wind speed threshold for snow grain movement) and prevailing wind directions ranging between 60° and 210°. It is not unusual for wind speeds at Willie Field to exceed 15 m s^{-1} during katabatic wind events, in which prevailing wind directions are mainly between 160° and 210°. Winds at Ferrell are strongly influenced by moderate katabatic winds with 44.1 percent of the observations exceeding 5 m s^{-1} and a dominant wind direction corridor from 210° with little directional variability for wind speeds greater than 5 m s^{-1}.

Primary tasks during the 1995–1996 antarctic field season were to sample the snow core and pit, analyze snow samples for glass microspheres, download MDS diagnostics and ambient temperature of buried instrumentation from a CR10 datalogger, upgrade instrumentation, and move one instrument to a new site. Instrumentation upgrades included installing new and more reliable pressure regulators (Victor, Inc.) in both MDS units and adding an ultrasonic snow depth gauge at Ferrell AWS. The Willie Field MDS was removed and installed on the polar plateau at automatic geophysical observatory 2 (AGO-2) (85.67°S 46.38°W) during the annual AGO service visit. In addition, an ultrasonic snow-depth gauge was also installed at AGO-2. The two field team members were D. Braaten and S. Delfelder.

Snow pit sampling at 1-centimeter (cm) resolution using cuvette sampling tubes is conducted to provide high-resolution information of microsphere horizons, allowing a detailed reconstruction of the time-dependent snow accumulation to be made. Snow pit locations were chosen based on winds during microsphere dispersals, prevailing winds, and the results of Sipre snow core surveys. High-resolution measurements of snow density are also obtained from these samples by measuring the volume of snow in the cuvette tube and the volume of water after melting. Assigning dates to microsphere horizons identified is not a simple process because not all microsphere horizons are found during snow pit sampling (even though they might be found during the snow core survey), and the local snow surface height can vary by several centimeters because of the intermittent presence of surface features (e.g., ripples and sastrugi). The accumulation measurements derived from snow stakes illustrate this local variation in which area snow accumulation varied between 7.9 and 17.5 cm with a mean variation of 13.9 cm for Willie Field and Ferrell. As a result, horizons of the same microsphere color found at slightly different depths in two different snow pits are not necessarily from different dispersal events, and the same color microspheres found at roughly the same depth in different snow pits might actually be from different dispersal events.

To overcome this inherent uncertainty in dating the microsphere horizons, the vertical snow density distribution and the depth of visually observed ice layers were used to normalize the depth of microsphere horizons to one of the snow pits designated as the reference pit. The primary consideration in choosing the reference pit was identification of the glass shard horizon indicating the start of the survey period. No attempt was made to match an entire accumulation profile with the reference profile because local accumulation is often influenced by formation and movement of surface features resulting in different relative accumulation rates during the year. Once the microsphere horizons identified in the snow pits have been normalized, dates are assigned to the horizons based on the known times of dispersal for each microsphere color, counting forward in time from the glass shard horizon, and counting back in time from the snow surface at the time of snow pit sampling. Figure 1 shows the snow depth derived with the ultrasonic snow gauge data, along with the microsphere derived dating of the profile.

Short-term mass accumulation rates at each site were determined using the microsphere dating information and the detailed snow density data. Figures 2 and 3 show the calculated mass accumulation rate since initial instrument deployment for Willie Field and Ferrell, respectively. The overall mass accumulation rate was very similar at both sites, with Ferrell having a larger integrated accumulation rate in 1994 and Willie Field having a larger integrated accumulation rate during 1995. No consistent relationship was found between mass accumulation rate and mean wind speed for a given period, implying that high wind speeds do not necessarily reduce the mass accumulation rate in areas with an unlimited upwind supply of mobile snow grains. The differences in mass accumulation rates seen at the two sites are likely governed by differences in the mesoscale precipitation patterns during this period.

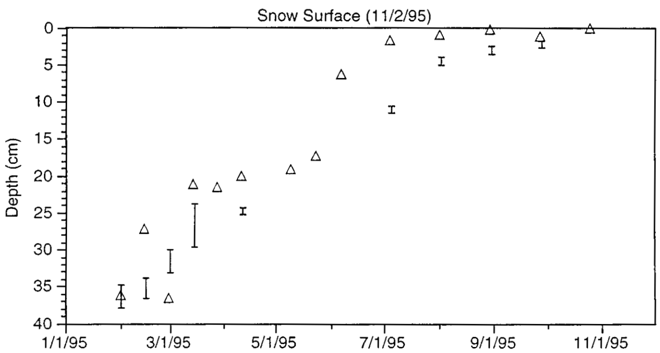


Figure 1. Willie Field AWS snow accumulation during 1995. The triangles give the snow surface height as a function of time from the ultrasonic snow depth gauge, and the vertical bars show the microsphere derived dating of the snow surface from a snow pit on 2 November 1995.

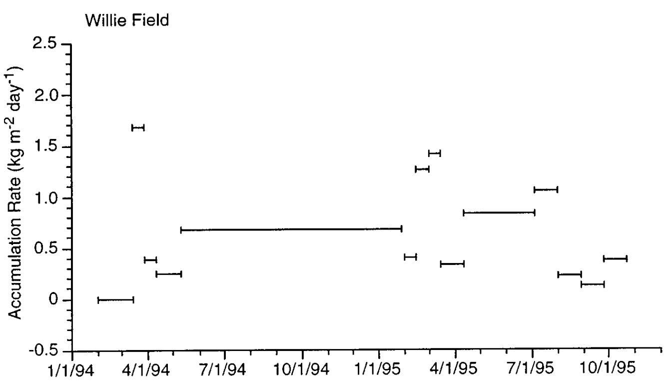


Figure 2. Mass accumulation rate at Willie Field AWS derived from microsphere dating information and snow density measurements since initial instrument deployment. (kg m^{-2} day^{-1} denotes kilograms per square meter per day.)

This research was supported by National Science Foundation grant OPP 94-17255.

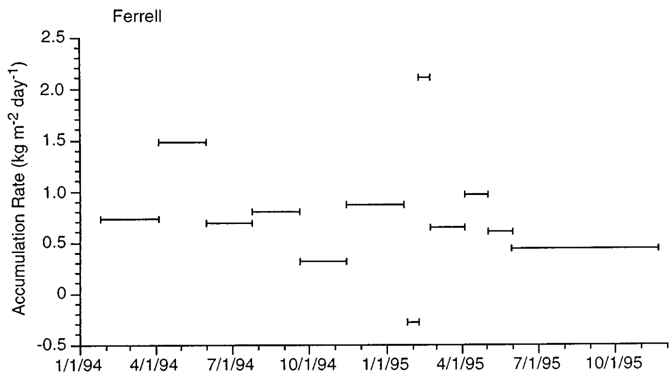


Figure 3. Mass accumulation rate at Ferrell AWS derived from microsphere dating information and snow density measurements since initial instrument deployment. (kg m^{-2} day^{-1} denotes kilograms per square meter per day.)

References

Braaten, D.A. 1994. Instrumentation to quantify snow accumulation and transport dynamics at two locations on the Ross Ice Shelf. *Antarctic Journal of the U.S.*, 29(5), 86–87.

Braaten, D.A. 1995. Assessment of snow accumulation and transport dynamics using glass microspheres. *Antarctic Journal of the U.S.*, 30(5), 331–332.

Holmes, R.E., C.R. Stearns, and G.A. Weidner. 1993. Antarctic automatic weather stations: Austral summer 1992–1993. *Antarctic Journal of the U.S.*, 28(5), 296–299.

Recent trends in stratospheric temperatures during austral springtime

WENYU DOU *and* THOMAS R. PARISH, *Department of Atmospheric Science, University of Wyoming, Laramie, Wyoming 82071*

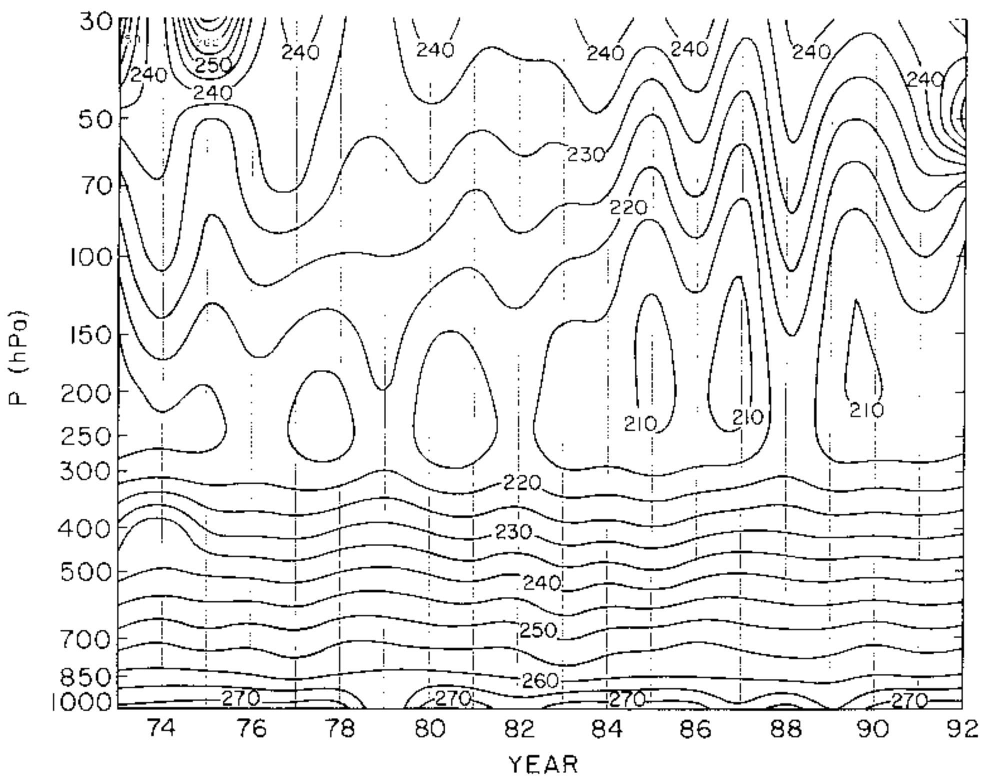
It has been over a decade since Farman, Gardiner, and Shanklin (1985) first reported on ozone depletion in the antarctic stratosphere. Subsequent measurements (e.g., Hofmann et al. 1987; Deshler, Hofmann, and Hereford 1990; Deshler and Hofmann 1991) have documented the austral springtime depletion of ozone and note that depletion occurs primarily in the 12–20 kilometer (km) layer and has been most severe in the 14–18 km range (Hofmann et al. 1987). Generally, ozone depletion commences in September and early October and recovery occurs in November.

Ozone strongly absorbs ultraviolet solar radiation and is a significant diabatic heat source for the stratosphere. Given the reduced concentrations of ozone observed during recent austral springtime periods, it is plausible to suspect that corresponding changes in the antarctic stratospheric temperatures have occurred. Temperature records derived from vertical soundings for 11 antarctic stations for the 20-year period 1973 to 1992 have been examined to detect whether such a definite trend of cooling in the antarctic stratosphere exists. As an example, the figure illustrates a time series of mean November temperature profiles at the east antarctic coastal station Davis (68.6°S 78.0°E) for the 1973–1992 period. A cooling trend is apparent in the lower stratosphere from approximately 200 hectopascals (hPa) to 50 hPa commencing in the early 1980s.

To test the significance of trends such as those illustrated in the figure, a series of statistical tests has been performed. Here, we report only on the results for the 70-hPa level for the month of November. Analyses of additional times and other standard isobaric levels can be found in Dou (1995). The 20-year record of sounding data shows that the average height of the 70-hPa level for an antarctic station is around 17 km, within the layer of severe ozone depletion. The 20-year period is divided into two segments: 1973 to 1984 and 1985 to 1992. For each segment and each station, the average temperature at 70 hPa in November and standard deviation are calculated. These results, along with the number of years with applicable records within each segment, are listed in table 1. Here, $\bar{t}_1 - \bar{t}_2$ denotes the difference between the average temperature during 1973–1984 and 1985–1992; standard deviations of temperature are given as s_1 for the period 1973 to 1984 and s_2 for 1985 to 1992.

Table 1 shows that the average 70-hPa temperature in November decreased from segment 1 (1973–1974) to segment 2 (1985–1992) in all stations considered. From a statistical standpoint, the situation is analogous to comparing the means ($\mu 1$ and $\mu 2$) from two populations with the variance σ_1^2 and σ_2^2. The distribution of their difference has the mean ($\mu 1 - \mu 2$) and the variance $\sigma_1^2 - \sigma_2^2$ (Miller, Freund, and Johnson 1990, *see* theorem 7.1). A conventional approach is to construct confidence intervals to test the null hypothesis. These intervals depend on the equality of the population variances σ_1^2 and σ_2^2, which can be evaluated by performing an F-test (e.g., Miller et al. 1990).

If the confidence interval contains 0, then the null hypothesis $\mu 1 = \mu 2$ cannot be rejected. This means no statistically significant difference exists in the means of the two populations at the given confidence level. In our case here, this may indicate that no statistically significant difference exists



Mean November vertical profiles of temperature at Davis for years 1973–1992.

Table 1. The average 70 hPa temperature (K) in November and standard deviation(s) during 1973–1984 and 1985–1992 for 11 antarctic stations. N denotes the number of applicable years within each segment.

Station	1973–1984			1985–1992			$\bar{t}_2 - \bar{t}_1$
	N_1	$\bar{t}_1$	s_1	N_2	$\bar{t}_2$	s_2	
Bellingshausen	9	225.0	3.4	7	223.3	4.6	–1.7
Casey	12	231.8	2.5	8	228.2	5.3	–3.6
Davis	12	229.2	3.4	8	222.3	5.7	–6.9
Halley	8	221.9	4.5	8	215.0	9.1	–6.9
McMurdo	11	231.3	6.3	8	226.0	9.5	–5.3
Mirnyy	11	231.5	2.9	7	227.2	4.7	–4.3
Molodez	12	225.6	4.0	7	218.9	4.8	–6.7
Novolaz	10	220.5	2.7	7	217.6	5.9	–2.9
South Pole	12	226.4	5.9	8	219.9	11.5	–6.5
Syowa	11	224.9	3.7	8	217.5	4.6	–7.4
Vostok	5	226.2	1.6	7	222.6	9.2	–3.6

Table 2. The 95 percent confidence intervals for t_1–t_2 (K) in November at 70 hPa

Station	95 percent confidence interval for t_1–t_2 (K) in November at 70 hPa
Bellingshausen	(–2.6, 6.0)
Casey	(2.2, 5.0)
Davis	(2.6, 11.2)
Halley	(–0.8, 14.5)
McMurdo	(–2.3, 12.9)
Mirnyy	(0.5, 8.1)
Molodez	(2.4, 11.0)
Novolaz	(1.2, 4.6)
South Pole	(4.4, 8.6)
Syowa	(3.4, 11.4)
Vostok	(0.96, 6.2)

between the average temperature during 1973–1984 and 1985–1992. On the other hand, if this interval does not contain 0, then the null hypothesis must be rejected. Further, if both the upper and lower limits of the interval are greater than 0, then the alternative hypothesis $\mu 1 > \mu 2$ must be accepted and the drop in the average segment temperature is significant.

Table 2 shows that among the 11 stations listed in table 1, eight of them show statistically significant temperature decreases from segment 1 to segment 2 at the 95 percent confidence level. Such drops for Bellingshausen, Halley, and McMurdo are not significant. To verify that the drops in the average segment temperature can be related to the maximum ozone depletion level at 70 hPa, the same statistical tests were also performed on the 300 hPa and 30 hPa temperature in November (not shown). Results from the same statistical tests as described above indicate that none of the stations shows any statistically significant change in the average segment temperature either at 300 hPa or 30 hPa during November. Thus, the significant changes are restricted to the same general region that is subject to maximum ozone depletion.

This research was supported in part by the National Science Foundation grant OPP 92-18544.

References

Deshler, T., and D.J. Hofmann. 1991. Ozone profiles at McMurdo Station, Antarctica, in the austral spring of 1990. *Geophysical Research Letters*, 18(4), 657–660.

Deshler, T., D.J. Hofmann, and J.V. Hereford. 1990. Ozone profile measurement within the edge of and outside the antarctic polar vortex in the spring of 1988. *Journal of Geophysical Research-Atmospheres*, 95(D7), 10023–10035.

Dou, W. 1995. A climatological study of the antarctic upper air temperatures and circulations. (M.S. Thesis, Department of Atmospheric Science, University of Wyoming, Laramie, Wyoming.)

Farman, J.C., B.G. Gardiner, and J.D. Shanklin. 1985. Large losses of total ozone in Antarctica reveal seasonal ClO_x/NO_x interaction. *Nature*, 315, 207–210.

Hofmann, D.J., J.W. Harder, S.R. Rolf, and J.M. Rosen. 1987. Balloonborne measurements of the development and vertical structure of the antarctic ozone hole in 1986. *Nature*, 326, 59–62.

Miller, I.R., J.E. Freund, and R. Johnson. 1990. *Probability and statistics for engineers*. New York: Prentice-Hall.